Tenth Lecture

WOOD

Wood has been used and adapted by humans since the earliest recognition that they could make use of the materials they found around them. As they used it to meet a varying array of human needs, in peace and in war, in farming and in industry, people gradually came to understand something of the unique nature of wood. Its properties were first understood by experience, more recently by systematic research and refined observation. Wood is still essential to human life, but has evolved over the ages from a simple, readily available natural material to a modern industrial and engineering material, with a unique ability to contribute to human life both as a material for use and as a key element in the natural world of the forest.

The Nature of Wood

Wood is a natural product of the growth of trees. It is primarily composed of hollow, elongate, spindle-shaped cells that are arranged more or less parallel to each other in the direction of the tree trunk. This makes wood basically fibrous in nature and the characteristics of these fibrous cells and their arrangement in the tree strongly affect properties such as strength and stiffness, as well as the grain pattern of the wood.

Structure and Formation of Wood

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. This can be confusing, because the wood of some softwoods is harder than that of many hardwoods. For example, Scots pine and Douglas-fir are softwoods, but their wood is harder than that of poplar or mahogany, which are classed as hardwoods.

Botanically, the hardwoods are angiosperms, which refers to the fact that the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous in that they contain vessel cells (pores in the transverse section) that form tubes for transporting water or sap in the tree. Typically, hardwoods have broad leaves that, in temperate and semi-tropical regions are shed in winter. Botanically, softwoods are gymnosperms, which refers to the fact that the seeds are naked (not

enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements.
Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings. The actual time of formation of earlywood and latewood varies with environmental and growth conditions.
Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells). Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth.
Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood
structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis.
The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers

to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (μm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, lowmolecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propylphenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths. Some softwoods (*Pinus, Picea, Larix,* and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma.

The structure of hardwoods is much more complex and diverse than that of softwoods with at least four major kinds of cells: fibers, vessels, longitudinal parenchyma, and ray parenchyma. Fibers are shaped something like tracheids of softwoods, but are much shorter (<1 mm) and tend to be rounded in cross section. Their function is primarily mechanical support. Vessel elements are specialized conducting tissue, unique to hardwoods, shorter than fibers, and connected end to end. They appear on the transverse face of the wood as pores. In some species, e.g., oak (*Quercus),* these large vessels become blocked with tyloses as the sapwood changes to heartwood. Tyloses may also form as a result of injury or drought. Longitudinal parenchyma are thin walled cells whose function is primarily storage of nutrients. Hardwood rays are made up of from 1 to 30 cell wide bands of parenchyma, storage tissue, running radially in the tree. In some species, such as the oaks and beeches, these are clearly visible to the eye, in others they are scarcely visible. Figure 4 is a three-dimensional representation of a hardwood, showing these types of cells on the transverse, radial, and longitudinal faces.